Name: ______________________ Date: ______________________ Period: _____

Unit 2 Notes, Part 4: The Macromolecules

Ms. Ottolini, AP Biology

Part A: the properties of carbon

Big Questions

Why is Carbon a fundamental atom in biological systems?

How does the structure of carbon allow for functionally infinite complexity in the structure of molecules that contain it?

Why Carbon?

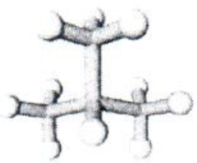
1. It's abundant
2. It's versatile

Carbon is tetravalent. → meaning it has 4 valence electrons, so it can make 4 single covalent bonds to satisfy its outer electron shell (filled = 8 electrons)

It makes 4 bonds to get stable

This leads to infinite variety → There are many possible molecules that can be made using carbon

Isomerism

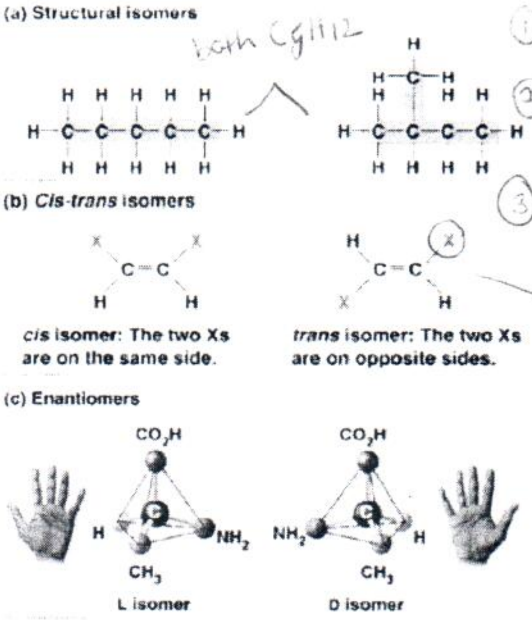


Isomers- Molecules with the same molecular formula, but different structures → And different structures mean different functions!

Any molecule more complex than propane has at least one isomer.

~~Isomerism is another example of an emergent property!~~ — Don't worry about this!

3 Kinds of isomers



1. Structural-
Same formula, different order.
2. Cis-Trans-
Same formula, different positioning around a double bond.
3. Enantiomers- → 2 forms: "L" and "D"
Same formula, mirror image positioning around a central carbon

Note: "X" is a place holder that could signify any molecule

About Enantiomers

Drug	Condition	Effective Enantiomer	Ineffective Enantiomer
Ibuprofen	Pain; inflammation	 S-Ibuprofen	 R-Ibuprofen
Albuterol	Asthma	 R-Albuterol	 S-Albuterol

I think "S" and "R" are used in place for "L" and "D"

Biological systems tend to use only one of any two enantiomeric forms.
All cells use D-sugars, and L-amino acids

Getting To Know The Functional Groups

Functional Groups modify the properties of organic molecules

List of Functional Groups (You must know these!)

Hydroxyl

STRUCTURE

(may be written HO—)

Alcohols (Their specific names usually end in *-ol*.)

NAME OF COMPOUND

EXAMPLE

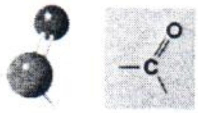
Ethanol

- Is polar as a result of the electrons spending more time near the electronegative oxygen atom. → this makes the oxygen slightly negative and the hydrogen slightly positive
- Can form hydrogen bonds with water molecules, helping dissolve organic compounds such as sugars.

FUNCTIONAL PROPERTIES

Carbonyl

STRUCTURE

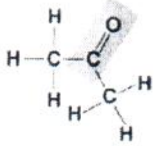


Ketones if the carbonyl group is within a carbon skeleton — several carbon atoms linked together in a chain

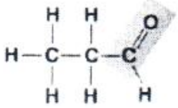
Aldehydes if the carbonyl group is at the end of the carbon skeleton

NAME OF COMPOUND

EXAMPLE



Acetone



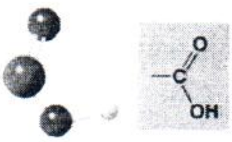
Propanal

- A ketone and an aldehyde may be structural isomers with different properties, as is the case for acetone and propanal. — the two molecules pictured to the left
- Ketone and aldehyde groups are also found in sugars, giving rise to two major groups of sugars: ketoses (containing ketone groups) and aldoses (containing aldehyde groups).

FUNCTIONAL PROPERTIES

Carboxyl

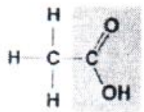
STRUCTURE



Carboxylic acids, or organic acids

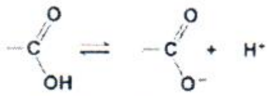
NAME OF COMPOUND

EXAMPLE



Acetic acid

- Acts as an acid; can donate an H^+ because the covalent bond between oxygen and hydrogen is so polar: — oxygen steals an electron from hydrogen, and H+ separates from the molecule



Nonionized   Ionized (charged)

- Found in cells in the ionized form with a charge of 1– and called a carboxylate ion.

FUNCTIONAL PROPERTIES

List of functional Groups (continued) (You must know these!)

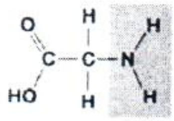
Amino

STRUCTURE

NAME OF COMPOUND

Amines

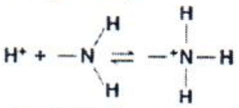
EXAMPLE



Glycine

FUNCTIONAL PROPERTIES

- Acts as a base; can pick up an H^+ from the surrounding solution (water, in living organisms):



- Found in cells in the ionized form with a charge of 1+.

Sulfhydryl

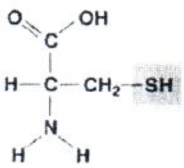
STRUCTURE

(may be written HS—)

NAME OF COMPOUND

Thiols

EXAMPLE



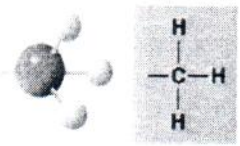
Cysteine

FUNCTIONAL PROPERTIES

- Two sulfhydryl groups can react, forming a covalent bond. This "cross-linking" helps stabilize protein structure. → This occurs in the tertiary (3°) level of protein structure (see protein section for a definition of tertiary structure)
- Cross-linking of cysteines in hair proteins maintains the curliness or straightness of hair. Straight hair can be "permanently" curled by shaping it around curlers and then breaking and re-forming the cross-linking bonds.

Methyl

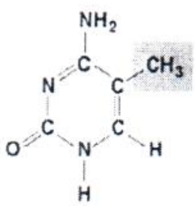
STRUCTURE



NAME OF COMPOUND

Methylated compounds

EXAMPLE



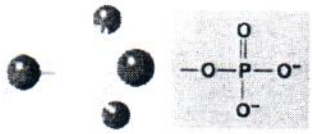
5-Methyl cytidine

FUNCTIONAL PROPERTIES

- Addition of a methyl group to DNA, or to molecules bound to DNA, affects the expression of genes. → By "expression," I mean the "use" of particular genes
- Arrangement of methyl groups in male and female sex hormones affects their shape and function.

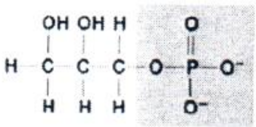
Phosphate

STRUCTURE



Organic phosphates — NAME OF COMPOUND

EXAMPLE

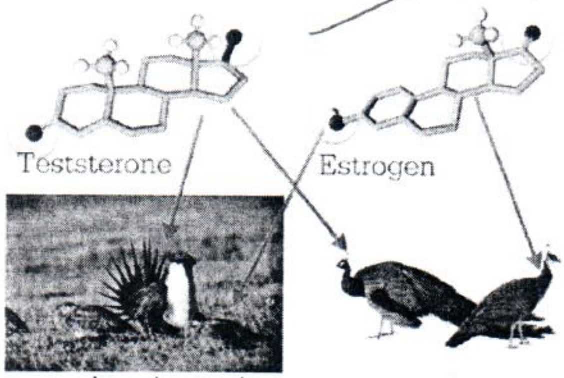


Glycerol phosphate

FUNCTIONAL PROPERTIES

- Contributes negative charge to the molecule of which it is a part (2– when at the end of a molecule, as above; 1– when located internally in a chain of phosphates).
- Molecules containing phosphate groups have the potential to react with water, releasing energy.

A little difference goes a long way!



These two molecules differ only in the functional groups attached to a common carbon skeleton of 4 fused rings. A difference in structure → a difference in function.

The entire difference in the physical appearance of genders is due to the effects of these two hormones!

Make Sure You Can

Explain how the structure of the Carbon atom leads to the emergence of complexity in carbon containing compounds

Identify and describe the properties of all of the functional groups discussed in this presentation.

Explain how each of the functional groups discussed contributes to the properties of the molecules that contain them.

Part B: the Macromolecules

Big Questions

How are the molecules of biological systems constructed?

Why are particular groups of molecules needed in biological systems?

How do the interactions of biological molecules lead to the emergence of life functions?

So, What's a Macromolecule?

- Big! (hence "macro")
- Made of few, common atoms
- Accomplish all life functions
- Put together in a special way
- Can be incredibly complex

4 Main Kinds

1. Carbohydrates
2. Lipids
3. Proteins
4. Nucleic acids

Building Macromolecules

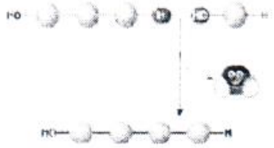
Except for lipids, macromolecules exist in two forms

- Monomer- the simplest unit
- Polymer- a large molecule made of repeating monomers

The movement between monomers and polymers is facillitated by adding/removing water.

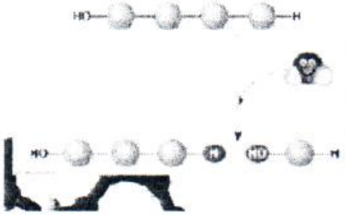
AKA - conversion

Dehydration Synthesis



Builds more complex molecules from smaller ones by removing 2 H & 1 O, and replacing it with a bond. → Adds monomers together to make a polymer
→ H_2O (water!) is lost
Water is produced!
Builds complexity ("anabolic")
Requires energy ("endergonic") & enzymes (more later)

Hydrolysis



Reverse of dehydration synthesis → Breaks down polymers into monomers
lysis = "breaking"
Water is needed! → H_2O (water) is added
Reduces complexity ("catabolic")
Releases energy ("exergonic")
Enzymes still required!

We will now take a tour

Things to focus on:

1. Structure & Function
2. Atoms Needed
3. Monomer
4. Polymer

Carbohydrates

General info:

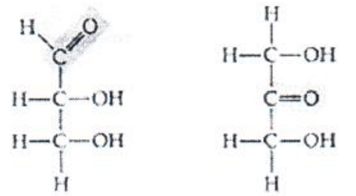
- "Sugars" & "Starches"
- Made of C, H, and O (1:2:1 ratio in monomers) → ex: Glucose = $C_6H_{12}O_6$ (simplifies to $C_1H_2O_1$)
- Used for short term energy storage & structure
- Monomers = "monosaccharides"
- Different Sugar monomers have different #'s of Carbon

3 carbon sugars = trioses

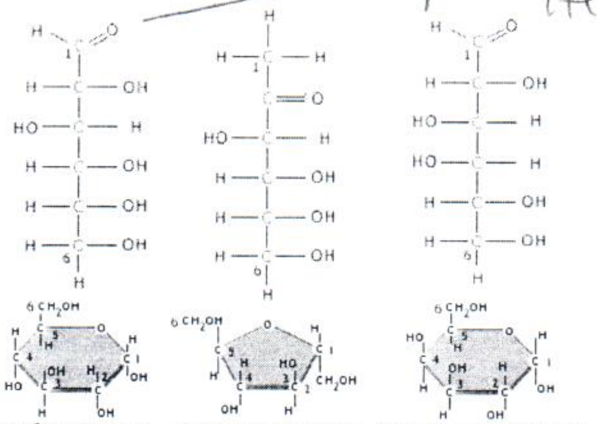
6 carbon sugars = hexoses (tend to form rings)

ALDOSES **KETOSES**

TRIOSE SUGARS ($C_3H_6O_3$)



Glyceraldehyde Dihydroxyacetone



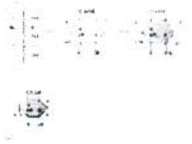
Glucose(Pyranose form) Fructose(Furanose form) Galactose(Pyranose form)

5 carbon sugar = pentose (tends to form rings)

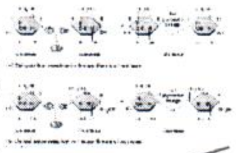
Monosaccharides & Disaccharides

These are the major carbohydrates used for energy

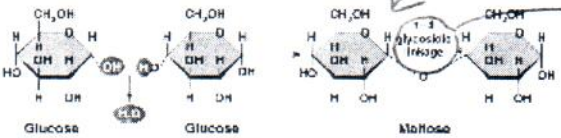
Hexose sugars are the most "famous" monosaccharides
Three kinds: Glucose, Galactose, & Fructose
They are typically shown as carbon rings.



Combine 2 by dehydration synthesis, and you get a "disaccharide"
(What are their molecular formulas?)
Glucose + Glucose = Maltose ("Malt sugar")
Glucose + Fructose = Sucrose ("Table sugar")
Glucose + Galactose = Lactose ("Milk sugar")

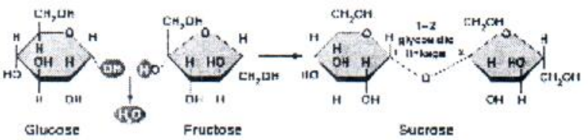


"zoomed in"



(a) Dehydration reaction in the synthesis of maltose

covalent bonds formed between 2 monosaccharides by dehydration synthesis are called "glycosidic linkages"



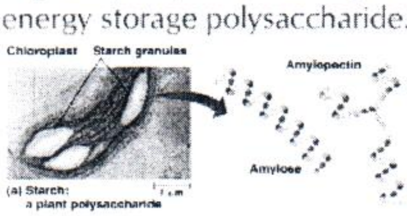
(b) Dehydration reaction in the synthesis of sucrose

Polysaccharides

Massive polymers of sugars are called "polysaccharides"
Glucose polymers have two main functions in organisms

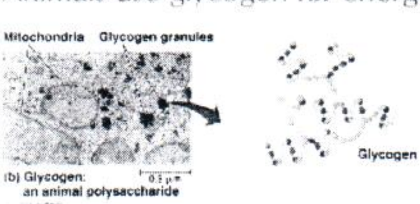
Energy Storage

Polysaccharides are great for short term storing of energy.
In plants, amylose ("starch") is the major energy storage polysaccharide.



(a) Starch: a plant polysaccharide

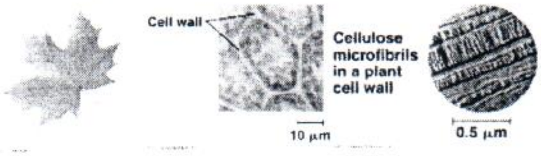
Animals use glycogen for energy storage



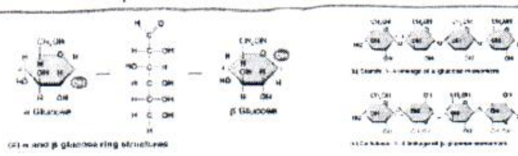
(b) Glycogen: an animal polysaccharide

Structural Support

Cellulose is the major component of plant-like cell walls.



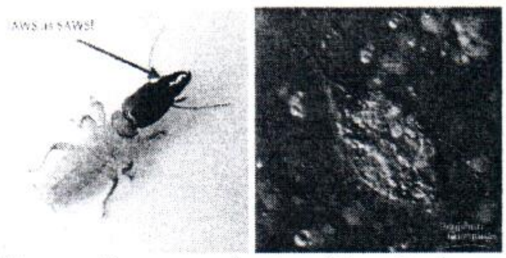
The difference between starch and cellulose is in the linkages between glucose units.
Starch = alpha linked. Cellulose = beta linked



The Problem of Herbivory

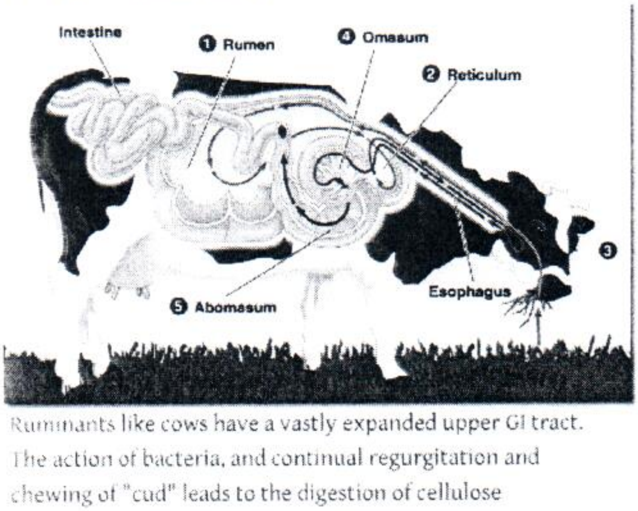
Herbivores need to digest cellulose.
Animals lack the enzymes necessary to break beta linkages
Several strategies are employed.

Termites!



The most famous wood-eater of the animal kingdom has a symbiotic relationship with a protist.
In exchange for a place to live (the termite gut), the protist does the cellulose digestion

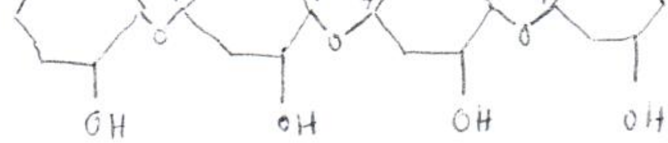
Ruminants!



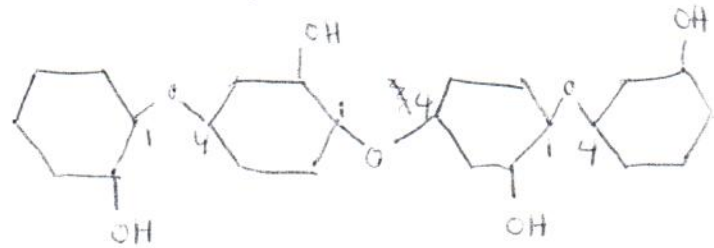
Ruminants like cows have a vastly expanded upper GI tract.
The action of bacteria, and continual regurgitation and chewing of "cud" leads to the digestion of cellulose

see page 73 in your textbook

Starch : 1-4 linkage of α (alpha) glucose monomers



Cellulose : 1-4 linkage of β (beta) glucose monomers



(the angles of the bonds that link the rings make every other glucose monomer upside down with respect to its neighbors)

↓

As a result of their glycosidic linkages, starch & cellulose have different overall shapes

starch = helical (spiral)

cellulose = straight, able to hydrogen bond with other cellulose molecules lying parallel to it → strong building material

Caecophores!

Caecophores like bunnies have an expanded lower GI tract. Food can not be regurgitated, but there is still a way to put partially digested cellulose back in to the animal...

Other Carbohydrates

Chitin = a modified polysaccharide.
Used in fungi cell walls, arthropod exoskeletons, and dissolving stitches!



Peptidoglycan = another modified polysaccharide.
Used in bacterial cell walls


Lipids

General info:

- Fats, Oils, Waxes
- Made of C, H, and O
- Used for long term energy storage & insulation
- No polymers. or monomers
- 3 major groups: triglycerides, phospholipids, & steroids



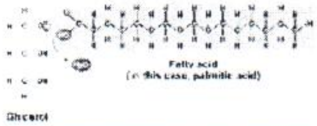
Triglycerides

- Triglycerides are made of one glycerol & 3 fatty acids.
- Connected by dehydration synthesis x 3 (ester linkages)

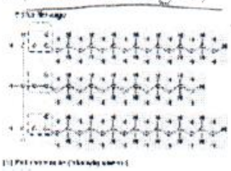
contains C, H, and O

contains carbon chains w/ H's branching off (Non-polar?)

covalent bonds between glyceral & each of the fatty acids



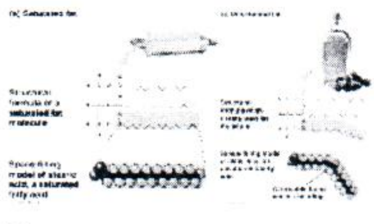
(a) One of three dehydration reactions in the synthesis of a fat



Saturated vs. Unsaturated

- Refers to the bonding of carbon in the fatty acids.
- Saturated = no double bonds between carbons.
- Unsaturated = at least one double bond.
- Influences shape which influences properties.
- ~~Oils vs fats~~
- Which ones stay liquid at lower temperatures? Why?
- Which ones are healthier for you? Why?

make sure you can answer this question

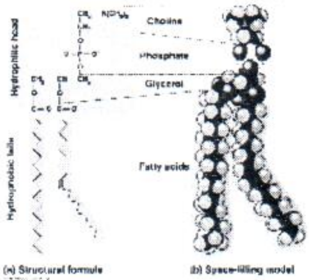


saturated fats = straight, stack neatly (solid @ Room temperatur

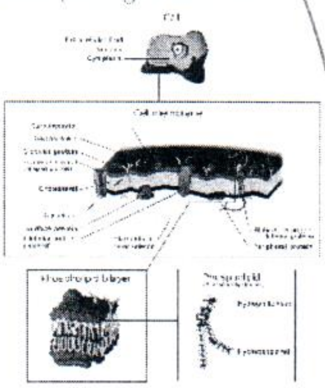
unsaturated fats = bent @ double bonds, stack less neatly (more space between the fatty acid chains → liquid @ Room Temperature)

Phospholipids

- Modified triglycerides. ~~Replace on fatty acid with a phosphate~~
- Makes the molecule have a polar and a non-polar region ("amphipathic")
- The major component of cell membranes (arranged as a "bi-layer" (double layer)



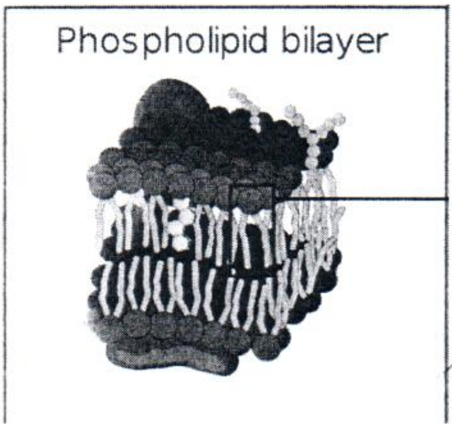
(a) Structural formula (b) Space-filling model



→ Add a phosphate group at the top + take away one fatty acid

→ polar Region = phosphate group (Head) glyceral

Non polar Region = fatty acids (Tails)



Why do phospholipids arrange themselves this way in the cell membrane?

(ex: testosterone & estrogen)

Steroids

→ other hormones are protein molecules

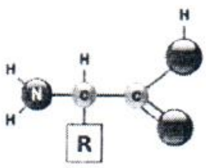
Cholesterol!

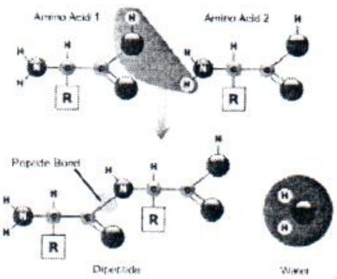
- 1 class (type) of hormones, & cholesterol.
- Notable structure = fused rings (carbon rings)
- Presence of different functional groups leads to different functions

Proteins

General info:

- The most complex biological molecules.
- Made of C, H, O, N & a little S
- Used to accomplish all life functions
- All proteins are polymers of amino acid monomers
- Amino acids are joined by "peptide bonds" → covalent bonds formed between amino acids by dehydration synthesis

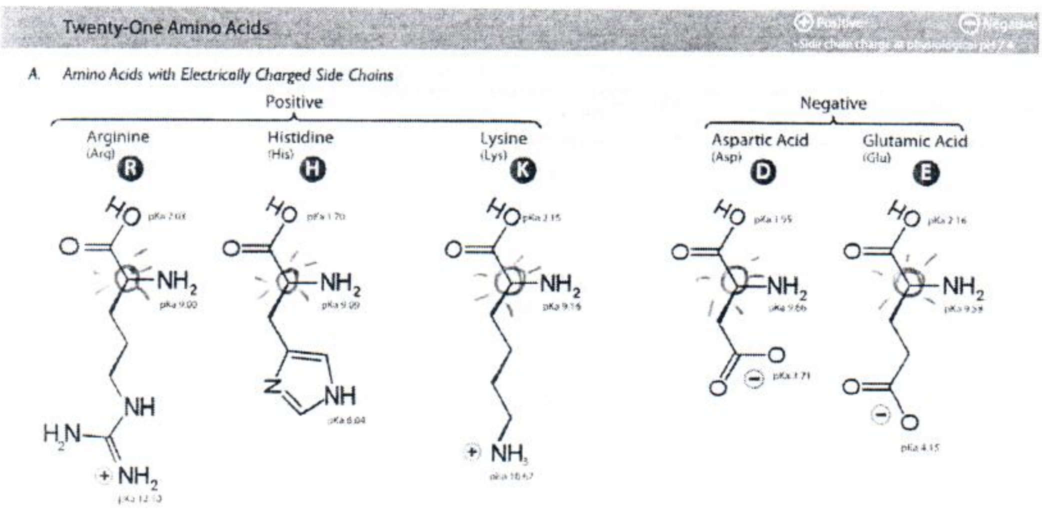




Amino Acids

(NH_2: $-N<^{H}_{H}$) ($COOH$: $-C<^{O}_{OH}$)

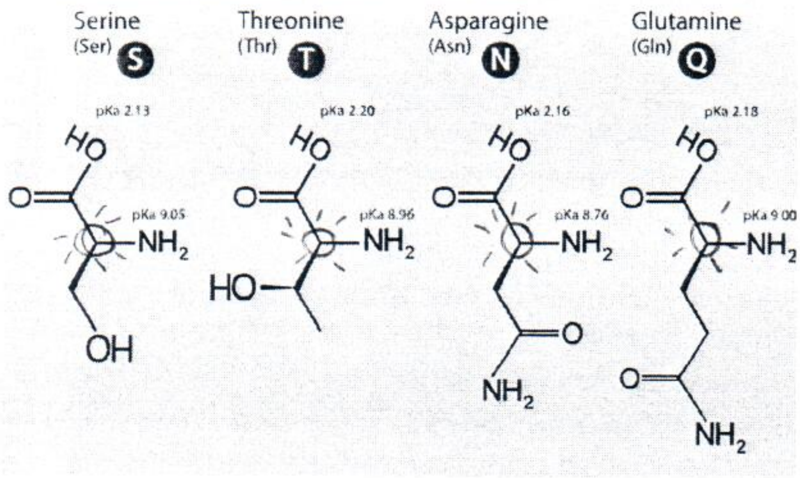
- There are 21 known amino acids used in biological systems.
- All amino acids contain an amino & carboxyl group, bonded to a central "alpha" carbon.
- Every amino acid differs in the structure of a variable group (symbolized as R) bonded to the alpha carbon.
- The structure of the R-group varies widely.



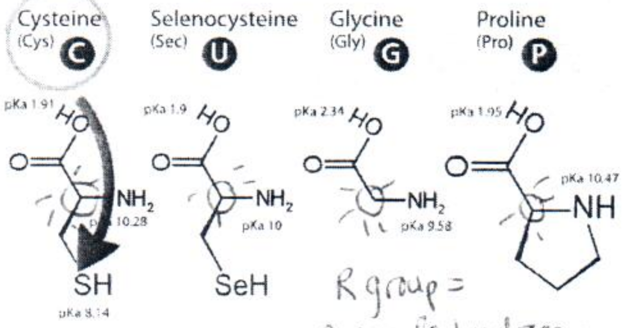
☼ = central carbon

* Note: You do not need to memorize the amino acids! Be able to predict their properties based on the functional groups in their "R groups"! *

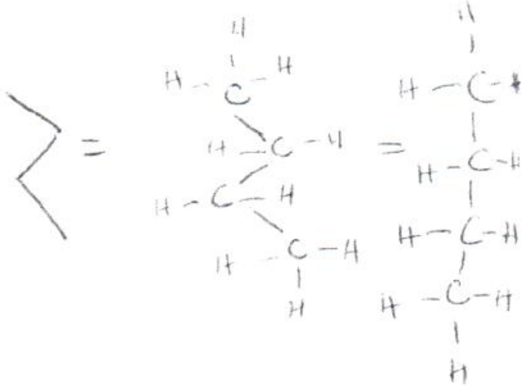
B. *Amino Acids with Polar Uncharged Side Chains*



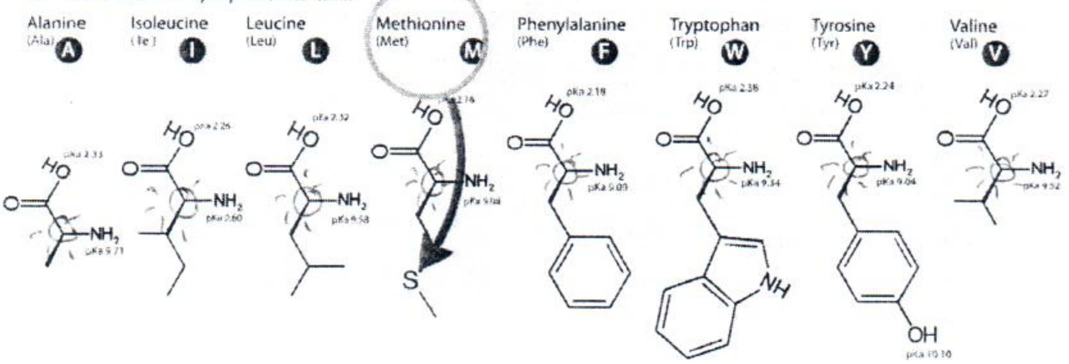
C. *Special Cases*

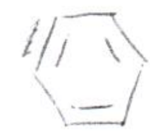


R group = a single hydrogen atom



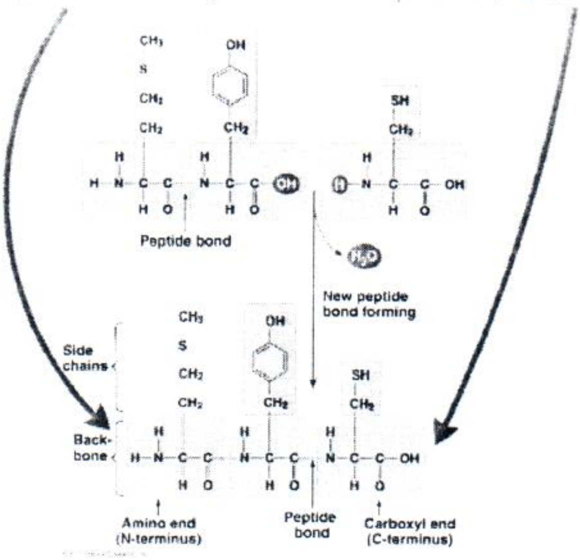
D. *Amino Acids with Hydrophobic Side Chain*





Benzene Ring (a ring of carbon atoms w/ 3 double bonds)

Chains of amino acids have a directionality, with an amino end ("N-terminus") & a carboxyl end ("C-terminus")

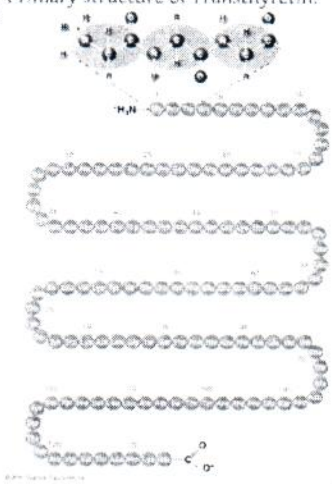


Protein Structure

Because of the diversity of amino acids, proteins have very complex 3 D structures. Generally, we can consider 4 levels of protein structure:

Primary Structure

Primary structure of Transthyretin:



What it is:
The sequence of amino acids in one polypeptide chain

How it happens:
Peptide bonds between amino acids.

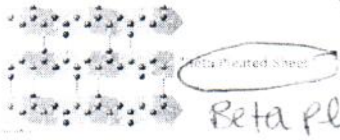
How does the cell "know" the order of amino acids?

The creation of polypeptides with a particular order of amino acids is based on the order of Nitrogen Bases in DNA

Secondary Structure

What it is:
Regular, repeating 3D structures found in all polypeptide chains.

Alpha Helix



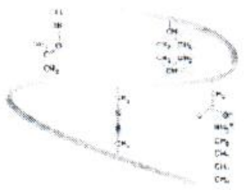
Beta pleated sheet

How it happens:
Hydrogen bonding between atoms in the CN backbone of the polypeptide (no R-groups involved)

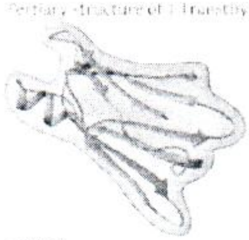
carboxyl group – amino group
backbone

Why do all proteins have similar secondary structures? – Important Question!

Tertiary Structure



What it is:
The specific 3D shape of a particular polypeptide chain (aka the "conformation")

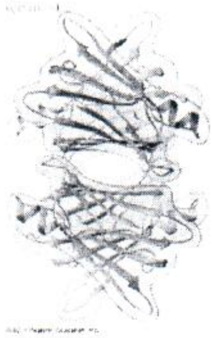


How it happens:
Interactions between R-group atoms with other R-groups and the local environments of the cell

What kinds of interactions can occur to determine tertiary structure? — Important Question!

Quartenary Structure

What it is:
The specific 3D shape of any protein that is made of more than one polypeptide chain (many are).
The only "optional" level of structure.



How it happens:
The overall structure when multiple chains form a functional protein.

> the same interactions occur as in tertiary structure, but this time they occur between different polypeptides

Why do some proteins consist of more than 1 polypeptide chain?

Protein Function

What do proteins do?

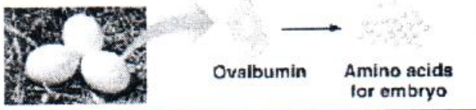
Generally speaking: Proteins are responsible for all life activities of the cell (and by extension, the organism, population, etc.)

Your book gives a pretty good overview:

Storage proteins

Function: Storage of amino acids

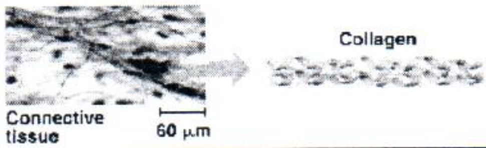
Examples: Casein, the protein of milk, is the major source of amino acids for baby mammals. Plants have storage proteins in their seeds. Ovalbumin is the protein of egg white, used as an amino acid source for the developing embryo.



Structural proteins

Function: Support

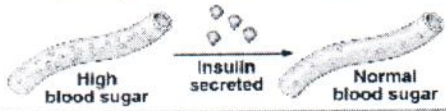
Examples: Keratin is the protein of hair, horns, feathers, and other skin appendages. Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastin proteins provide a fibrous framework in animal connective tissues.



Hormonal proteins

Function: Coordination of an organism's activities

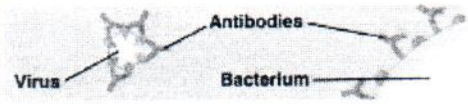
Example: Insulin, a hormone secreted by the pancreas, causes other tissues to take up glucose, thus regulating blood sugar concentration.



Defensive proteins

Function: Protection against disease

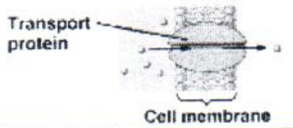
Example: Antibodies inactivate and help destroy viruses and bacteria.



Transport proteins

Function: Transport of substances

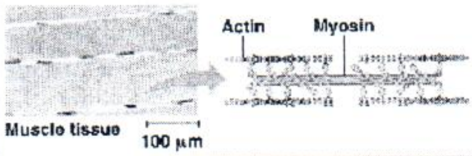
Examples: Hemoglobin, the iron-containing protein of vertebrate blood, transports oxygen from the lungs to other parts of the body. Other proteins transport molecules across cell membranes.



Contractile and motor proteins

Function: Movement

Examples: Motor proteins are responsible for the undulations of cilia and flagella. Actin and myosin proteins are responsible for the contraction of muscles.



Receptor proteins

Function: Response of cell to chemical stimuli

Example: Receptors built into the membrane of a nerve cell detect signaling molecules released by other nerve cells.

Enzymatic proteins

Function: Selective acceleration of chemical reactions

Example: Digestive enzymes catalyze the hydrolysis of bonds in food molecules.

An Illustrative Example

Sickle cell anemia: One example of the relationship between protein structure and organismal physiology (not the only one, by any means!)

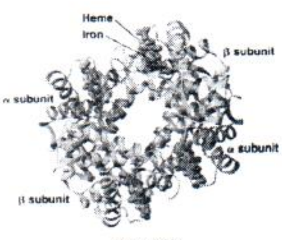
This is Hemoglobin!

It carries oxygen in your red blood cells

IT IS

CRAZY

IMPORTANT!

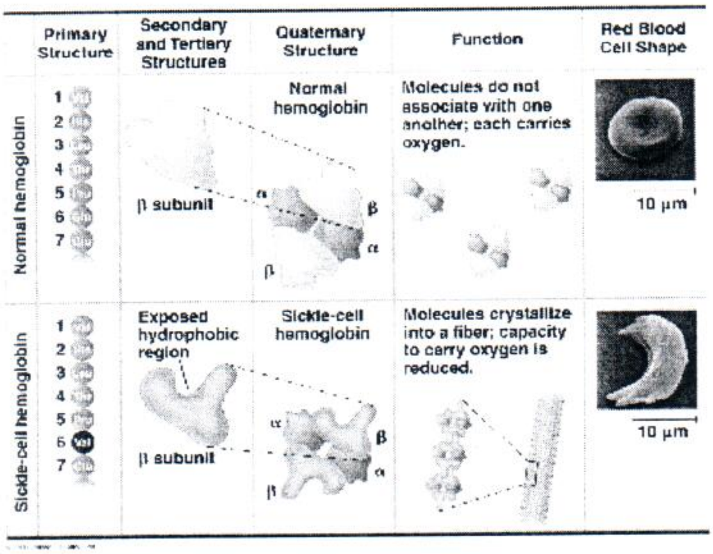


AKA "non polar"

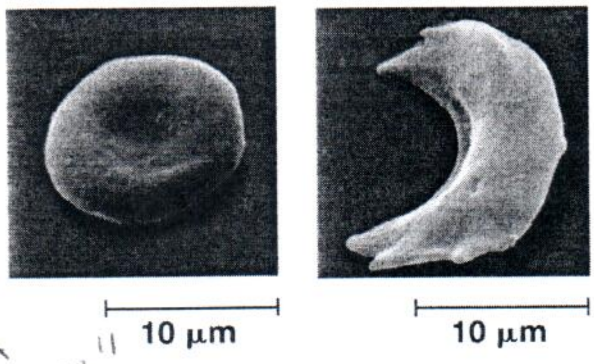
Some unlucky folks have a mutation that results from (an amino acid) valine (hydrophobic) replacing (an amino acid) glutamic acid (hydrophilic) in the beta chains of hemoglobin

AKA "polar"

OOPS!



This change in the structure of hemoglobin affects the function.
Sickle-cell hemoglobin gets clumpy, and the red blood cells change shape.
They don't carry as much oxygen, and get stuck in blood vessels.
Sickle-cell anemic people die at a young age from the disease.

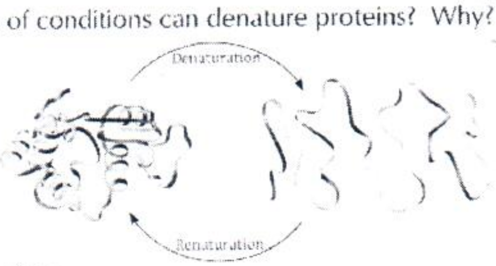


AKA "shape"

Denaturation

There is a direct relationship between a protein's conformation and its function.
If the conformation is altered, the function of the protein will also be altered.
Denaturation: Change in the structure of a protein.
Denatured proteins do not work well (if at all).

What sorts of conditions can denature proteins? Why? — Important Question!



Visualizing Proteins

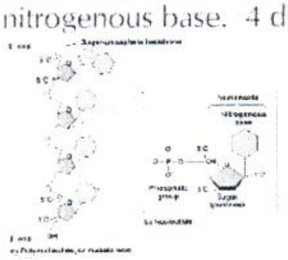
Because of their complexity, studying protein structure & function ("proteomics") can be overwhelming.

(FREE!) Computer modeling software is frequently used to help visualize important structural aspects.

Nucleic Acids

General info:

- The information storage molecules for biological systems.
- Made of C, H, O, N & P
- 2 kinds of nucleic acids: DNA & RNA
- All nucleic acids are polymers of nucleotides.
- Nucleotides consist of a phosphate, a pentose sugar, and a nitrogenous base. 4 different bases in DNA & RNA



see page 87 in the book for a more clear image

DNA vs. RNA

While similar in structure, there are a few key differences which lead to major differences in function.

Pentose:

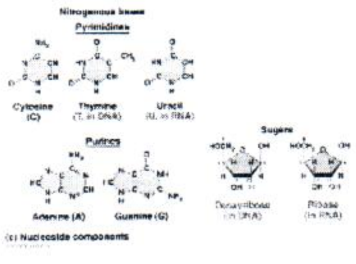
- DNA = deoxyribose RNA = ribose

Bases:

- DNA = Adenine, Thymine, Guanine, Cytosine
- RNA = Adenine, Uracil, Guanine, Cytosine

Strands

- DNA = 2 strands
- RNA = 1 strand



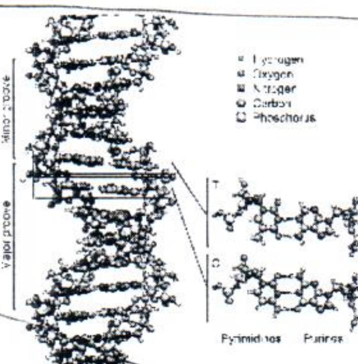
DNA: Deoxyribonucleic Acid

DNA serves 2 functions in all life on Earth:
1. Stores information about the primary structure of proteins, and the sequences of RNA molecules.
2. Is heritable.

the order of amino acids

can be passed down from parents to offspring

DNA Structure:
- 2 chains of covalently bonded nucleotides, from sugar to phosphate... ("phosphodiester bonds")
- Chains are bonded to each other by hydrogen bonds between N Bases.
- A bonds to T, G bonds to C.
- Purine (A,G) always opposite Pyrimidine (T,C)



phosphodiester Bonds a type of covalent bond that forms between Nucleotides by dehydration synthesis

why is this the case? what is the difference between a purine and a pyrimidine?

Discovery of DNA Structure

The most important biological discovery of the 20th century (and arguably, the 2nd most important ever).
Watson & Crick - published the paper
Wilkins & Franklin - did the X-Ray diffraction work
Some controversy about ethics of Watson & Crick.
Nobel Prize (1962)- Watson, Crick, & Wilkins (Franklin was dead)

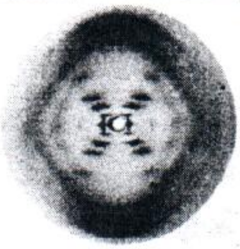

James Watson & Francis Crick

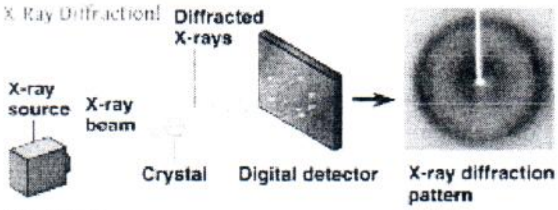

Maurice Wilkins


Rosalind Franklin

Photo 51: X marks the helix!


Photo 51: X marks the helix!



X Ray Diffraction!


RNA: Ribonucleic Acid

RNA serves many functions for life:
1. Transmits and translates DNA information into protein.
2. Many enzymatic and regulatory functions.
3. 1 kind of DNA, ~15 types of known RNA at current (3 main types)

serves as the intermediate molecule between DNA and protein
DNA → RNA → protein

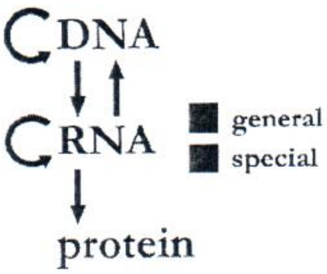
Turns out it is MUCH more interesting than DNA is.

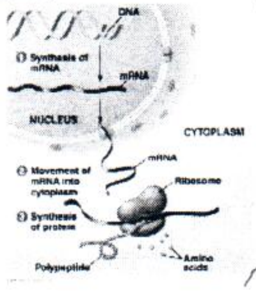
RNA Structure:
- less stable than DNA.
- 1 strand, but base-paring can still occur (A bonds to U)

can result in RNA molecules that are not "straight"

Information in Biology

- Biological systems are process matter, energy, & INFORMATION.
- The information stored in DNA moves to RNA before some of that information finally directs the construction of proteins.
- This is known as the "Central Dogma" of molecular biology.
- It will be the underpinning of the most important biological advances during your lifetime (it already is!)





what does this image show?

Make sure you can

Identify the structures of the monomers and polymers of the four major classes of macromolecules.

Diagram the synthesis and hydrolysis of carbohydrates and polypeptides.

Explain the biological functions of all of the molecules discussed in this presentation.

Explain the emergence of all four levels of protein structure.

Describe the role of general role of nucleic acids in living systems.